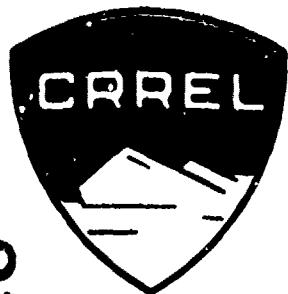


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THE EFFECT OF LOW VISIBILITY ON THE PERFORMANCE OF VEHICLE OPERATORS

Ronald Liston

August 1972

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U.S. ARMY MATERIEL COMMAND
BY

**CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE**

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An experimental program to identify the relationship between visibility conditions and operator performance is discussed. Average speed in negotiating a controlled course is taken as the measure of operator performance. The method to measure visibility is discussed. It is shown that despite use of a contrived test course and artificially reduced visibility, the results appear valid. It is also shown that the relationship between visibility conditions and average speed can be represented with a simple, second order equation.		
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PREFACE

This report was prepared by Mr. Ronald Liston, Research Mechanical Engineer, of the Applied Research Branch (Mr. A.F. Wuori, Chief), Experimental Engineering Division (Mr. K.A. Linell, Chief), U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL).

The work was performed as a part of the AMC Mobility Research Program in support of the AMC 1971 Vehicle Mobility Model.

To complete the design of the experiment and the conduct of the field test required extensive support from Mr. Francis Gagnon and Mr. Ben Hanamoto. Both made many useful inputs and suggestions, and provided new equipment where needed.

Messrs. G. Abele, B. Hanamoto, and A.F. Wuori and Dr. W.L. Harrison, Jr. all provided valuable inputs and comments during the preparation of this report.

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THE EFFECT OF LOW VISIBILITY ON THE PERFORMANCE OF VEHICLE OPERATORS

by

Ronald Liston

INTRODUCTION

The development, verification and expansion of a computerized, analytical model of the man-vehicle-terrain system are the primary objectives of the mobility research program currently being pursued by and for the U.S. Army Materiel Command. A first generation model has been developed jointly by the Waterways Experiment Station and the Tank-Automotive Command. With one exception, the model does not consider specific geographic areas such as deserts or jungles. Instead, it attempts to use general relationships between such things as the vehicle and soil or vegetation. Then, by measurement of the characteristics of the soil or vegetation in a specific area, the model can take on a geographic orientation.

Because of many singular properties of terrains associated with cold regions, it was recognized that a geographically oriented submodel would be required to describe vehicle performance in snow-covered terrain, muskeg, thawing soils, and other surface and vegetative conditions peculiar to cold regions. The Cold Regions Research and Engineering Laboratory was given responsibility for the development of such a submodel. As a first step, a model was prepared that considered the operation of tracked and wheeled vehicles in deep snow. Analysis of the overall problem of operating in the cold regions environment revealed several conditions requiring study before they could be incorporated in the submodel. Among them was the reduction of visibility by blowing snow, fog, or similar low temperature phenomena. This topic is the subject of the short study reported herein.

BACKGROUND

In order to design an experiment that would reveal the effect of low visibility on operator performance, it was necessary to examine the way that the operator uses knowledge gained from visual observation.

Aside from monitoring engine instruments, the primary uses of visual cues are for path selection and path keeping. Under off-road conditions, the path keeping role is normally trivial, only becoming critical when the route requires precise positioning, as when negotiating narrow gaps between trees or moving through a narrow defile. Under most circumstances, visual cues are used almost entirely for path selection.

There appear to be several factors that establish the degree of difficulty involved in path selection. The obvious ones are speed and visibility. In each case, the effects are clear: at high speed the operator cannot scan adequately to identify the best path, and under conditions of degraded visibility the characteristics of a "good" path are difficult to distinguish. It is important that we recognize at the outset that there are two types of visibility degradation: obscuration such

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as that produced by fog or severe precipitation, and low light intensity such as that associated with night operation. With few exceptions, off-road operation at night is so difficult that vehicles are led by a guide on foot so that the problem needs little investigation. In this special case, speed is so low that the vehicle can be considered ineffective. Thus, we need concern ourselves only with the problems of obscured vision without extremely low ambient light intensity.

Among the other factors affecting path selection are the operator's familiarity with the terrain and his apprehension. If the driver has an intimate knowledge of the terrain, he will be aware of the types of obstacles that he can expect and will be able to identify the best route with relative ease. Since he knows the types of obstacles that will pose a problem, he can concentrate on specific parts of the terrain, thereby reducing his scanning chore and permitting a higher speed. If other factors such as ride demand a lower speed, as is often the case, then the advantage of being familiar with the terrain is lost.

Another factor is the effect of apprehension or fear. Fear can induce severe tunnel vision which results in the driver seeing only the spot at which he is staring and completely missing all other visual cues. If the driver is only apprehensive rather than fearful, the effect is greatly reduced but nonetheless remains.

The introduction of driver emotions into the problem probably opens a can of worms as we are now involving individual personality traits. People tend to react differently to threatening situations and individuals don't necessarily react consistently. To be afraid, we need to recognize a threat and its consequences. The fact that the average automobile driver reacts more strongly to the threat of a traffic ticket than to the threat of a disabling accident is witness to the difficulty of attempting to include this factor as a test variable.

The test procedure described in the next section evolved after several trials. The difficulty in designing the experiment involved the introduction of realism in an artificial situation. That is, it was necessary to include the equivalent of terrain obstacles that the driver would have to search for. In the real world, the operator is rewarded for identifying an obstacle by not getting immobilized or by not being severely jolted upon hitting it. The jolt or the immobilization serves as his punishment if he fails to observe the obstacle. Thus, the driver usually makes a significant effort in the path selection task because it is important to his well-being. The introduction of a threat of ill consequences from poor path selection was a major source of concern in developing the test procedure.

TEST PROCEDURE

Objective

The objective of this test was to identify the relationship between visibility and vehicle operator performance in such a way that the results could be used to modify the snow submodel of the AMC 71 Vehicle Mobility Model.

General description

The test procedure that was finally used differed in many ways from that originally conceived. Details of the initial test procedure will not be discussed; however, the major changes which were required will be examined.

The test technique consisted of determining average vehicle speed through a standard course under conditions of varying visibility. It was necessary to design the course in such a way that it would require both path selection and path keeping tasks for successful negotiation. It was simple to provide for the path keeping task by arranging a test course with specific lanes to follow. The path selection task was considerably more difficult to provide for realistically.

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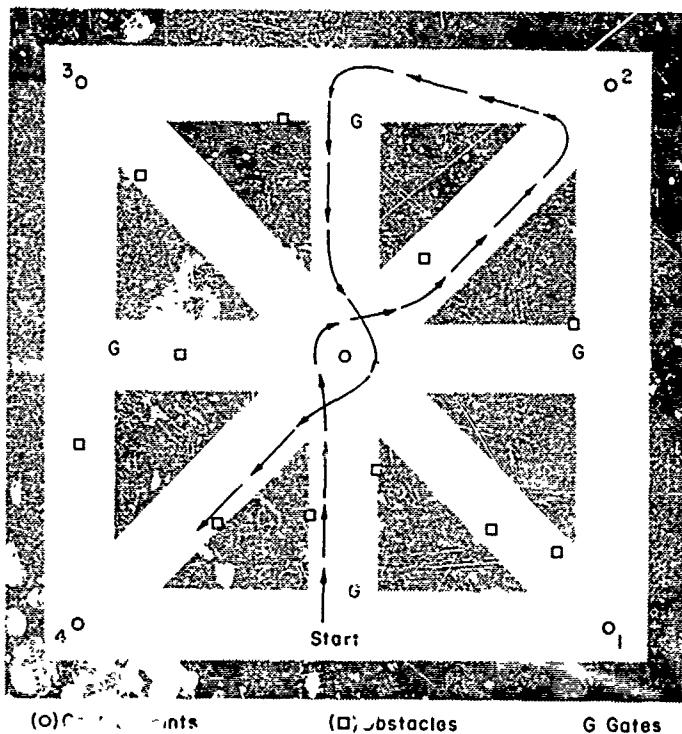


Figure 1. Test course layout showing the beginning of a test run.

After several attempts, the following scheme was developed. The test course (Fig. 1) consisted of four gates, five control points, and twelve "floating" obstacles. There was a central control point and four corner control points.

At the central control point a card displaying the number of one of the four corners was used to direct the driver to a corner control point. These cards had a 6-in.-high numeral on a black background (Fig. 2). The numeral was easily distinguishable except in extremely low visibility conditions. At the corner control point another card was displayed on a 6-ft post. It consisted of a 12 × 12-in. piece of white fiberboard with a 4 × $\frac{3}{4}$ -in. light green arrow painted in the center of it (Fig. 3). These control cards, which were designed to be hard to see, could be rotated so that the arrow pointed left or right. During test runs these corner control cards directed the vehicle toward either of two gates. Thus as the operator approached each corner control point he did not know which way he was to turn until he could discern the arrow.

The "floating" obstacles consisted of 12 × 12-in. perforated fiberboard painted various colors to blend with the environment. They were "floating" in the sense that their location was varied for each test run and they were partially concealed, requiring the driver to stay alert in order to pick them out. When an obstacle was spotted, the operator was required to stop the vehicle, dismount, pick up the obstacle, remount, and then continue. If the driver did not see the obstacle, he was assessed the time equivalent to picking it up and given a penalty that was highly untechnical but disturbing enough to be a strong motivation for careful path selection. Obviously the operator did not select the path on the basis of avoiding the artificial obstacle but he expended a reasonable proportion of his control energy and time in seeking obstacles that would in a real situation have forced him to deviate from a straight line path. The object of requiring the operator to retrieve the obstacle was to account for the time that would normally have been lost in negotiating or circumventing it.

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Figure 2. Center control point control card.

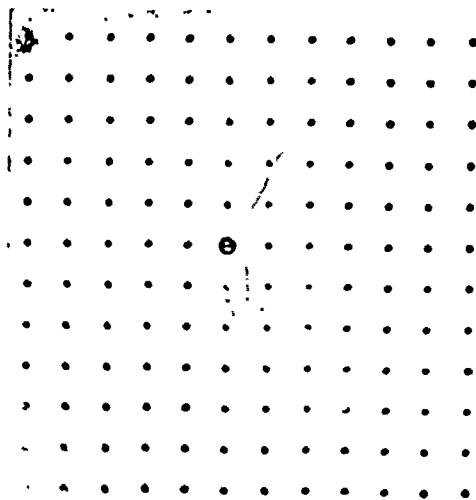


Figure 3. Corner control point control card.

It was not possible to rely on natural changes in the visibility level in the conduct of the test. Although there is a surprising spread in the ability of different people to distinguish objects at any given level of illumination, the spread is not broad enough to identify the relationship between visibility and performance. Thus, to attempt to rely on natural visibility variations would have required that the test cover a long time period in order to test in such conditions of reduced visibility as snow, fog and rain.

It was decided, therefore, to depend on artificial means to reduce visibility. The initial idea struck upon was the use of one of the gadgets used for training pilots to fly on instruments. This consists of an orange colored cellophane cover for the windshield and side windows and blue colored sunglasses. The combination prevents the pilot from seeing anything outside the aircraft but does not affect his ability to see the instruments. This idea was abandoned for practical rather than conceptual reasons. Goggles with variable intensity lenses were used instead (Fig. 4). The goggles were originally developed for antiaircraft gun crews who were required to look into the sun while tracking enemy aircraft.

There was some confusion at the outset as to what was meant by the term visibility. The first thought, and therefore the basis for the initial test procedure, was that light intensity and visibility were synonymous. Thus, visibility was to be measured with an ordinary photographic light meter set to read for an ASA film speed of 25. A backup measurement was to consist of the distance at which a standard target could be distinguished. The error in this can be seen in Figures 5 and 6. The light meter reading for Figure 5 indicated that the camera setting should be f7 and $\frac{1}{250}$ second. The meter reading for Figure 6 indicated a setting of f12 at $\frac{1}{250}$. Despite the significantly lower level of light intensity for Figure 5, the visibility conditions are much better than those of Figure 6.

It was thus necessary to utilize a method of visibility measurement that was only concerned with how well the driver could see. The corner control cards were made by a trial and error process so that the arrow was barely discernible with the naked eye from a distance of approximately 200 feet under noontime illumination on a cloudless day. Although the preceding statement implies careful control and analysis in the preparation of the control card, the establishment of the size of the arrow and the intensity of the paint was a matter of the light conditions which existed on the day that the card was prepared. If the card had been prepared on a different cloudless day no doubt a slight difference in the card would have occurred. The only consequence of this difference would be that the distance scale of the test results would have been slightly modified.

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Figure 4. Variable-density goggles to provide obscured vision.



Figure 5. Clear, low light level condition.

The method selected to measure visibility was as follows: immediately prior to a test run, the driver set the variable density goggles (hereafter referred to simply as goggles) to any desired setting and moved to a position in front of the Number 1 control point where he was able to see the arrow clearly. Obviously he would begin the routine far enough away from the card that he would have to move toward it. When he reached the point at which he could see the arrow clearly, one of the other test team members would change the direction of the arrow and the driver would point in the direction that the arrow was aimed. If the driver was able to point correctly for five settings of the arrow, it was concluded that he was located at the proper distance for that goggle setting. The distance between him and the control card was taken as the measure of visibility.

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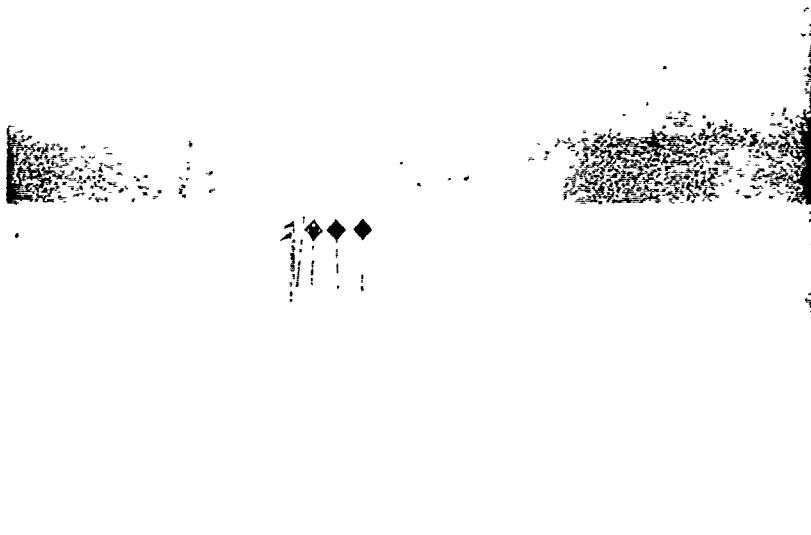


Figure 6. Obscured, high light level condition.

Equipment

Test vehicle. The test vehicle (Fig. 7) was a modified M29C personnel carrier popularly known as the Weasel. The modification consisted of removal of all of the flotation tanks and had no effect whatever on the test. There is nothing unique about the Weasel that caused its selection as a test vehicle. It was available along with a good supply of spare parts and is easy to operate so that it would not distract the driver from his path keeping and path selection tasks. However, the same comments would apply to several other vehicles, implying that the specific vehicle chosen to conduct the test was of relatively minor importance. The vehicle was timed several times during the traverse between the Keweenaw Field Station, where it was based, and the test site. The average cross country speed for three operators driving on this "course," having no hidden obstacles, was 9.8 mph.

Measurement of time and distance. Time was measured with stop watches. The test team consisted of three people so that two members timed the vehicle as it negotiated the test course while the third acted as driver. Distance was measured with an electric counter (Fig. 8). The counter was operated from a pulse generated by the closing of a microswitch mounted on the vehicle and contacting a cam driven by a flexible cable connected to the drive sprocket. Thus, each revolution of the drive sprocket registered as one unit on the counter. Since the sprocket was 9 in. in diameter, the error in measuring distance was ± 2 feet. Because the Weasel is steered by braking one track, a counter was mounted on each track.

Course. The course was located about four miles from the U.S. Army Tank-Automotive Command's Keweenaw Field Station adjacent to the Houghton County Memorial Airport near Houghton, Michigan. The course was laid out on a flat, open area (Fig. 9). Figure 10 shows the card at Corner Control Point 2. The snow depth can be gauged from the fact that the card was mounted on a post approximately six feet high. The test was conducted in the late fall, prior to and during the initial snowfalls of the winter season, and also during the very late winter. Figure 10 was obviously taken during the late winter test.

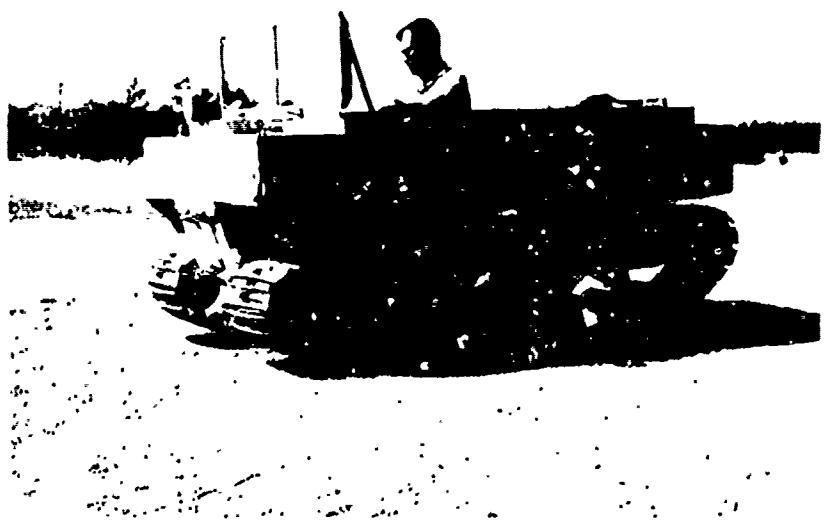


Figure 7. Test vehicle: Modified M29C Weasel.

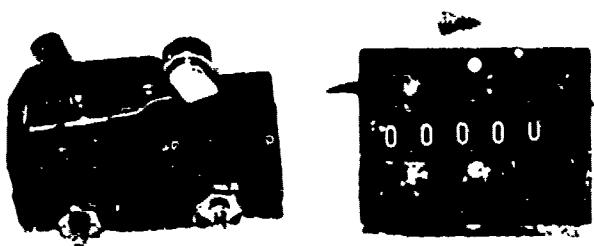


Figure 8. Electric counter with microswitch.

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Figure 9. Test vehicle on course. Corner control point 1 may be seen at right edge of photograph.



Figure 10. Corner control point 2.

Operators. Three test drivers, F. Gagnon, B. Hanamoto and R. Liston, were used to assure that the results would not indicate some peculiarity of the driver. There were distinct differences in visual acuity of the drivers so that a given goggle setting would produce visibility distances of, say, 40 ft for one, 50 ft for another and 60 ft for the third. This is of no consequence since the

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visibility distance, nor the goggle setting, was the parameter being considered. Each operator has had extensive experience operating off-road equipment so that driver technique was not a factor affecting the results.

Conduct of test

The first step in the conduct of a run was placement of the obstacles. The 12 obstacles were placed on or very close to the course, sufficiently camouflaged to be difficult to see but still visible.(Fig. 11). The obstacles were placed by the two test members who were not scheduled to drive.

As soon as the obstacles were placed, one team member and the driver established the visibility distance for the test while the third team member set the four corner control cards to point in the appropriate directions. If two corner control cards were to point to the same gate, one or more obstacles were withheld initially and placed after the driver went through the gate for the first time.

Figure 1 depicts part of a typical test run. After setting the distance counter to zero, the operator simultaneously signaled the timekeepers and started the vehicle. As he proceeded along the test lane, he scanned from side to side to identify obstacles (Fig. 12). When he observed an obstacle, he dismounted, picked up the obstacle, remounted and continued. If he failed to see the obstacle, he was assessed an 18-second penalty. As he continued along the course, the center controller displayed a control card (Fig. 2) directing him to a corner control point. In the example in Figure 1, the driver was directed to corner control point 2. The driver proceeded around the center control point and down a path to the corner control point. The driver continued along the path to the corner control point until he could distinguish the direction of the arrow, in this case left, then drove to the gate, through it and up to the center control point where he was directed to a new corner control point, in this example number 4. The operator proceeded around the center control point toward corner control point 4. During the entire run the driver was constantly searching for obstacles and picking them up upon discovery.



Figure 11. Typical obstacle on test course.

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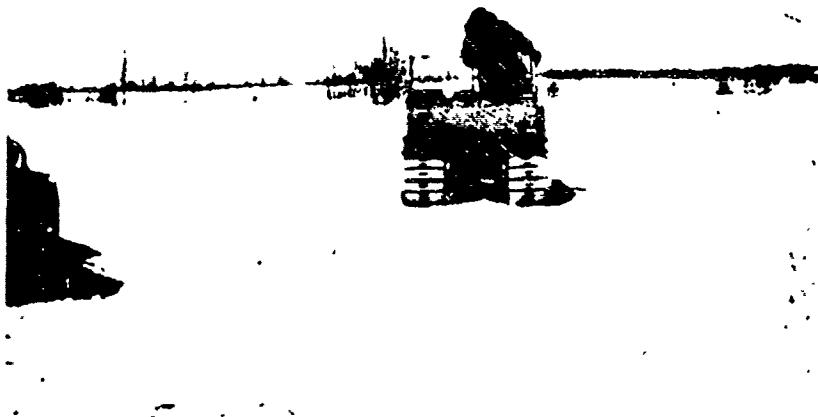


Figure 12. Operator on course with severe vision obscuration.

The test was continued until all corner control points and gates had been negotiated. The timing ended when the driver went through the fourth gate and drove past the center control point. The distance traveled, the time required to negotiate the course, the visibility distance, and the number of obstacles missed were all recorded.

The members of the test team switched duties and a new test run was started. In some cases, it was suspected that visibility conditions had changed during the test run. In this situation, the visibility distance was remeasured. In no case were significant changes found.

Time on course and distance traveled were measured to permit calculation of average speed, which was taken as the definition of performance.

TEST RESULTS

Two results emerged from the tests. The first is that the method developed to relate performance and visibility appears to work acceptably well. All involved with the design of the test had misgivings at the outset over the use of an artificial test course and artificially reduced visibility. We were concerned that the combination would produce a situation so unrealistic that the operator would behave completely atypically. As one of the operators, the writer can attest to the fact that the apprehension resulting from fear of missing an obstacle or of getting off course was very close to the response generated by a natural, unfamiliar off-road terrain. For example, when operating at very low levels of visibility, the feeling was almost exactly equivalent to operating in severe fog or driving snow. In fact, two operators were unable to complete the course at a visibility distance of 20 feet because of severe vertigo. The sensation was equivalent to operating in a whiteout.

The second result was that the relationship between vehicle speed and visibility distance can be represented fairly well by a second order equation (Fig. 13). Standard curve fitting techniques using the method of least squares were used to establish the relationship.

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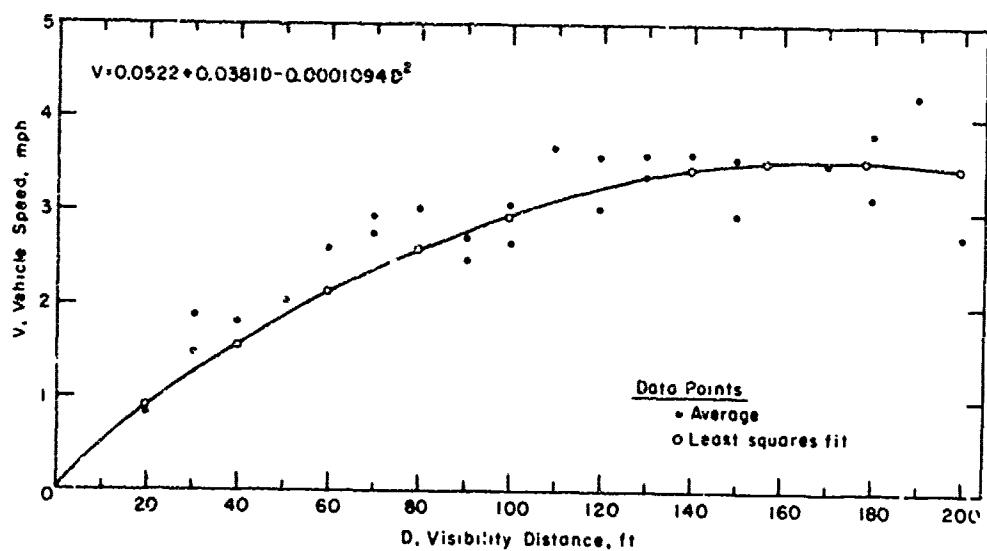


Figure 13. Relationship between vehicle speed and visibility distance.

$$V = (522 + 381D - 1.094D^2) \cdot 10^{-4}$$

where:

V = average maximum possible speed under the conditions, mph

D = visibility distance, feet.

It is suspected that this relationship is not strongly vehicle-dependent but this would require field testing to verify. No doubt the fit of the curve could be improved by using a higher order equation but the match produced by the second order seemed quite good enough.

It is important to note that the maximum average speed achieved in the test program was 3.4 mph. This maximum average speed is the speed which can be developed with no ride or visibility limitations. As mentioned previously, the average cross-country speed developed between the field station and test site was 9.8 mph. But the latter speed was achieved over terrain familiar to the drivers and devoid of unknown obstacles. Thus, the 9.8 mph figure represents speed limited by severity of ride while 3.4 mph represents speed limited by the path selection task.

It is strongly suspected that although the ride limitation is highly dependent upon the suspension of a vehicle for a given terrain, the lower limit imposed by the path selection task will be significantly less variable.

APPLICATION OF RESULTS

In order to introduce the results of this test into the AMC Mobility Model, it will be necessary to establish the distribution of visibility distances over an extended period of time. It will also be necessary to establish the distribution for several climatic types to identify any geographically dependent characteristics. Knowing the most probable visibility distance and both the maximum and minimum distances, it will be possible to introduce the visibility distance limits to speed as a subroutine in the computer model. The velocity limit imposed by the visibility level would then be compared to other limiting factors such as ride, soft soil, or power and would be identified as critical or not critical.

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However, it appears that the limit found in this test is so low that tests in natural terrain conditions with either naturally or artificially reduced visibility are justified. If equivalent results are found when a vehicle is operated in terrain completely unfamiliar to the operator, then the path selection task must be viewed as critical to performance. Previous tests strongly imply the dominance of the path selection task. One specific test involved measurement of the time required to drive a vehicle of comparable size to the Weasel through a wooded area under two conditions: operating on virgin snow where path selection was required and operating on the path formed by the first pass. It required three times as long to make the first pass, where path selection was required, as the second pass, where only path following was required. Since the path selection task appears critical to performance, it would appear that deterioration of ability to perform this task will also be a significant factor to consider.